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Calculating Antenna-Installation Wind Loading

For general reasons of safety and in particular for eventual insurance claims, every householder should possess the wind-loading calculations for his antenna installation. A subsequent investigation by the claims assessor, upon finding an unauthorized construction, will certainly result in the damage costs falling on the owner of the antenna.

1. INTRODUCTION

It is well-known that every antenna has a wind loading surface which is directly proportional to its mechanical dimensions and which is normally given by the manufacturers. The wind loading may be expressed in various units, e.g. in sq.ft. or in square metres (1 m² = 100 dm²). Modern catalogues use the Newton (N) as the unit of force and a few examples are given in table 1.

Conversion: $1 \text{ ft}^2 = 0.093 \text{ m}^2$ $1 \text{ m}^2 = 10.76 \text{ ft}^2$ 1 kp = 9.8 N

From the known or calculated cross-sectional area of the surfaces exposed to the wind, the wind loading P can be easily obtained. This is dependent upon the wind speed, i.e. from the dynamic pressure (Q) arising therefrom.

If the antenna is less than 20 m above ground or upon a free-standing mast or roof, a Q of 800 N/m² may be expected at a windspeed of 120 km/h.

If the antenna is mounted more than 20 m above ground it may be expected to encounter winds of 140 km/h, i.e. a dynamic pressure Q of 1100 N/m². In exposed areas such as mountains, hills or coastal areas, a wind speed of 160 km/h, i.e. 1440 Nm² should be provided for.

The dynamic pressure Q is proportional to the square of the wind speed v. When the value is not given, it can be calculated from table 2.

Many manufacturers give the wind velocity in miles per hour (mph).

Conversion: 1 km = 0.62 land miles 1 mile = 1.61 km



Frequency band and antenna type at 120 km/h at 160 km/h 2-m-Yagi 4 element WISI-UY 07 67 N 120 N 2-m-Yagi 12 element WISI-UY 12 105 N 190 N 2 m cross Yagi 10 element Jaybeam 5 XY 105 N 190 N 2 m cross Yagi 20 element Jaybeam 10 XY 198 N 360 N 70-cm-Multibeam, 48 ele. JAYBEAM MBM 48 93 N 170 N 70-cm-Helical, 7 turns, ANDES, circular 69 N 125 N 23-cm-Helical, 10 turns, ANDES, circular 41 N 75 N 24-cm-Long Yagi (ATV) SHF 6964 120 N 216 N 5-Band-Quad 2 ele. v.d.Ley 28-14 MHz (0.8 m²) 1380 N 770 N (0,93 m²) 1610 N 6-Band Multibeam 7 ele. Sommer XP 507 900 N 6-Band Polybeam 6 ele. FRITZEL FBDX 66 940 N 1690 N 3-Band Polybeam 3 ele. FRITZEL FB 33 400 N 720 N 4-Band Minibeam 3 ele. MINI-PRO. RK 3 (1,6 ft2) 143 N 257 N 4-Band Miniguad 2 ele. MINI-PRO. HQ 1 (1,5 ft2) 134 N 241 N 5-Band vertical 1 element HY-Gain 18 AVT 125 N 226 N

Table 1: Examples of wind-loading values for proprietary antennas

2. CALCULATIONS

The total wind loading of an array comprises the addition of the individual loadings of all the antennas in the array, the cross-members, outriggers, rotors and the total length of the mast.

A stability rule of thumb has it, that the greatest loading or fracture possibility will occur at the topmost supported point. This loading should never exceed the maximum permitted bending moment of the tube employed.

Examples are given in table 3 for the strengths applicable, in various directions, for various types of steel.

Dynamic pressure	800 N/m ²	1100 N/m ²	1440 N/m ²
Wind speed	120 km/h	140 km/h	160 km/h
in % of 120 km/h	100 %	138 %	178 %
Multiplication factor	1	1,38	1,78
in % of 140 km/h	73 %	100 %	131 %
Multplication factor	0,73	1	1,31
in % of 160 km/h	55 %	76 %	100 %
Multiplication factor	0,55	0,76	1

Table 2: Conversion of dynamic pressure Q to wind speed v



Type	Draw - Compression	Bending	Torque	0.9 x Bending (a)
ST 37	180	180	120	162
ST 42	200	210	140	189
ST 50	220	240	150	216
ST 60	280	300	180	270
ST 70	330	350	210	315

Table 3: Yield points for various grades of steel (DIN 17100) to forces (N/mm²) applied in the given directions

The factor of safety of proprietary tubes should be taken as being some 10 % below the values in table 3 (absolute limit $\beta_{0.2}$). This reduced bending moment rating is designated by the Greek letter (Sigma) σ .

From the quotient, bending moment M_B and bending tension $\sigma=(0.9~x$ stretch limit $\beta_{0.2}$) the resistive moment W_B is obtained for the bending moment at the point under consideration

$$W_B = \frac{M_B}{0.9 \, \beta_{0.2}} \quad \text{in cm}^3$$
 (1)

$$W_B = \frac{\pi}{32} \cdot \frac{(D^4 - d^4)}{D} = \frac{D^4 - d^4}{10 D}$$
 in cm³

where D = external dia in cm d = internal dia in cm (2)

Ø D/d in mm	W _B in cm ³
32 / 28	1,36
42/38	2,44
45 / 40	3,4
50 / 46	3,54
48 / 43	3,94
50 / 40	7,38
60 / 52	9,41
60 / 50	11,15
76 / 70	12,30
100 / 92	28,36

Table 4: Section modulus of various tube diameters

The larger the tube's cross-sectional area is, the greater is its ability to withstand a given bending moment. This important rating may be determined for all proprietary antenna tubing (examples in table 4) by the following calculations.

Combining formulae 1 and 2 the four quantities may be obtained: -

$$M_{B} = \frac{0.9 (D^{4} - d^{4}) \beta_{0,2}}{10 D}$$

as well as D, d and $B_{0.2}$

The bending moment at a given point is not known as a rule but it may be obtained from the product of the wind loading and the height of the free-standing mast.

$$M_B = P_R x H/2 = 1.2 DQH x H/2 = 0.6 DQH^2$$
 (3)

where D = the tube's external dia

H = the total height of the mast

Q = the dynamic pressure at a given wind speed

The factor 1.2 is the CW value of a tube. **Table 5** gives examples of permissible bending-moments according to DIN 0855.

The permissible antenna wind loading is obtained after deducting the wind load due to the mast tube and by that of the rotor mounting on the mast.



ext./int ø	max, bending moment
ø 32/28 mm	400 Nm
ø 42/38 mm	720 Nm
ø 48/43,4 mm	1080 Nm
ø 48/43 mm	1160 Nm

Table 5: Examples of the permitted bending moments for various steel tubing (ST 60-2)

If the calculated maximal antenna wind loading is not sufficient, then a tube of greater diameter must be employed. On no account should more antennas be mounted on a mast that is being supported by only one set of guy ropes or support bearings. The guy ropes should not be included in any stability calculations at all. The purpose of guy ropes is: —

- They should inhibit mechanical oscillations

 which could have a resonant frequency. A resonant condition could quickly lead to the destruction of a property calculated antenna system.
- 2.Inhibit undue movement of the mast swaying in the wind could also be the cause of signal variations on the radio link in both send and receive directions apart from considerations of mechanical stability (see the article by Ewald Schleenbecker, DK 9 ZN, in the German magazine CQ-DL 5/82).

The following wind loading formulae are applicable: -

$$P_{1/2} = (H_{1/2} \cdot P_{100\%})/H_{100\%}$$
(4)

where H100 % is the total height

P100 % is the given wind loading

H_{1/2} is the height of the antenna above the guyed point or support bearing.

The wind loading P for a steel tubular mast: -

$$A = DH is P_B = 1.2 AQ$$
 (5)

The total wind loading is simply the sum of all the individual wind-loadings: —

$$P_{tot} = P_1 + P_2 + P_3 + P_4...$$
 (6)

Unfortunately, manufacturers seldom give data about the maximum permissible wind loading of their mast tubing. More often, only data concerning the maximum bending moment or just the type of material is given.

Calculating the bending moment of individual antennas is very simple. The given wind load of the antenna is multiplied by the height at which the antenna is mounted above the guying point (or support bearing). The total bending moment at the guyed point is then the sum of all the imdividual bending moments of the antenna, cross beams, the rotor and the mast tubing itself.

$$M_{Byst} = P_1 H_1 + P_2 H_2 + P_3 H_3 + ...$$
 (7)

Using the manufacturers given value for $\beta_{0.2}$ (Beta 0.2) or σ (Sigma) it is also possible to calculate the total permitted axial load that a tube will withstand. The formulae 1 and 2 are used as well to obtain the maximum permissible bending moment of the tube at the guyed point.

The bending moment of the antenna is calculated using formula 7 and it is compared with the result above for verification.

3. REGULATIONS

The height of the antenna installation will normally be restricted by regulations.

According to VDE 0855, corresponding to DIN 57855, antennas may be constructed on a single tube of no higher than 6 metres whereby the total bending moment (at the clamped point) can on no account exceed 1650 Nm. The minimal clamped length is 1/6 of the total length of the tube. Even when the free length above the clamped point is no more than 1 metre, the sum of all the wind loadings (times the height) should not exceed this value.

All constructions, whose values exceed these two limits, require a static calculation and certificate from a structural engineer. This particularly applies for lighting or power masts of from 10 to 20 metres in height.



4. EXAMPLE

A practical example will now be considered. This is pictured in fig. 1 and a planning diagram is shown in fig. 2.

The mast comprises two sections of 2 metre long "plug and socket" tubing of 48 mm external diameter and 43 mm internal diameter. Both tubes are affixed axially and supported at a point 2.5 metres from the top of the installation. A HQ 1 is mounted at the top i.e. 2.5 metres above the support bearing and a 2 metre cross-Yagi and a 70 cm Helical antenna are both mounted 1.5 metres above the support bearing (see fig. 2). Ignoring the structural considerations, it is better from an RF point of view to place the shortwave antenna above the UHF antenna in order to obtain better radiation characteristics.

This arises because the 14 MHz antenna mounted only 0.5 metres above the roof level would correspond to a 144 MHz Yagi mounted only 5 cm above the roof's surface, when seen from an electro-magnetic field point of view. The proximity of the roof at this height would totally modify the angle of shoot of the HF antenna.

As the subject antenna installation is mounted on the roof of a house 10 metres above ground level and in a relatively sheltered situation, the wind pressure was fixed at 800 N/m² at a wind speed of 120 km/h and for a height of max. 15.5 metres of the HF antenna.

Antennae data:

70 cm Helical with 7 turns: P1 = 69 N 2 m Cross-Yagi with 16 elements: P2 = 160 N

According to the rules, the antennas at a height of 1.25 m above the support bearing is half that of the total mounting height of 2.5 m and this corresponds therefore to about half the above data P1 = 35 N and P2 = 80 N. The manufac-

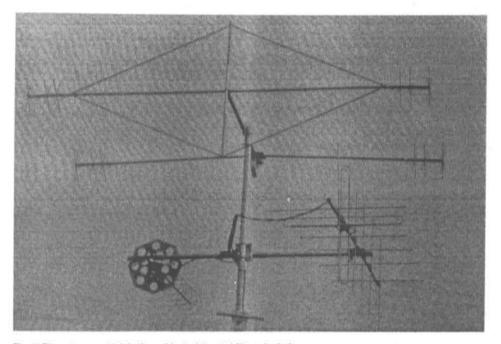


Fig. 1: The antenna which is the subject of the stability calculations



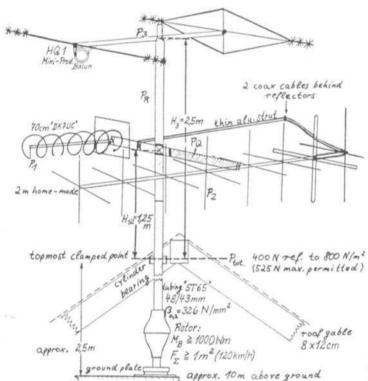


Fig. 2: Dimensional diagram of the subject installation shown in fig. 1

turers data (table 5) shows the tube of length 2.5 m capable of withstanding an antenna wind loading of 410 N (max).

The shortwave antenna is mounted at the full height of 2.5 metres and is subject to the full wind loading. As the antenna was manufactured in USA, the given data had to be converted to metric.

$$1.5 \text{ ft.}^2 \triangleq 1.5 \times 0.093 \text{ m}^2 = 0.14 \text{ m}^2$$

 $P3 = 0.14 \text{ m}^2 \times 800 \text{ N/m}^2 \times 1.2 = 134.4 \text{ N from (5)}$

The cross boom carrying the two UHF antennas is also subject to half the wind load as it is mounted at 1.25 m.

With A = DL and (5) gives for a 48 mm tube: -

$$P_Q = 1.2 \text{ DLQ} = 0.048 \text{ m x } 1.5 \text{ m x } 1.2 \text{ x}$$

 $\times 800 \text{ N/m}^2 \times 0.5 = 34.5 \text{ N}$

The wind loading of the mast tube is also calculated from formula 5:

$$P_B = 1.2 \text{ DLQ} = 0.048 \text{ m} \times 2.5 \text{ m} \times 800 \text{ N/m}^2 \times 1.2 = 115 \text{ N}$$

(The wind loading of the tube has already been subtracted in table 6)

The total wind load of the installation is then

$$P_{tot} = P_1 + P_2 + P_3 + P_Q + P_R = 399 N$$

This value of about 400 N lies well below that of the maximum permissible antenna wind loading of 525 N. Either a small parabolic dish antenna could be added, or the HF antenna can be considered as safe at a wind force of up to 120 N — either could be contemplated with this amount of spare loading to play with.

A parabolic dish mounted at 1.7 m has a wind load of 176.5 N according to formula 4.



By using formula 5 and the formula for the area of a circle $A=\pi r^2$, the diameter of the dish may be calculated: -

$$r_s = \sqrt{\frac{P_4}{1.5 \pi Q}} =$$

$$\sqrt{\frac{176 \text{ N} \cdot \text{m}^2}{1.5 \pi 800 \text{ N}}} = 0.216 \text{ m}$$

$$D_u = 0.43 \, \text{m}$$

free length max, antenna wind load 1140 N 1.5 m 740 N 1.5 m 2.0 m 540 N 2.5 m 410 N 3.0 m 320 N 260 N 3.5 m 4.0 m 210 N 4.5 m 170 N 5.0 m 130 N

Table 6: Permissable wind loads for various guyed (supported) antenna heights using 48/43 mm tubing

If instead, a 0.5 m dish antenna is used, it may only be mounted at a height of 1.4 m (max.).

Another method of calculating the above example is to add the individual bending moments according to formula 7.

$$M_{B \text{ tot}} = 69 \text{ N} \times 1.25 \text{ m} + 160 \text{ N} \times 1.25 \text{ m} + 134.4 \text{ N} \times 2.5 \text{ m} + 69 \text{ N} \times 1.25 \text{ m} + 69 \text{ N} \times 1.25 \text{ m} + 115 \text{ N} \times 1.25 \text{ m} = 852 \text{ Nm}$$

This value is still smaller than the maximal permitted bending moment for our 48/43 mm tube of 1160 Nm. This means that the construction is permitted.

This means of calculation also shows that the installation could be additionally loaded with a small parabolic dish.

$$M_{sp}$$
 176 N x 1.7 m = 299 Nm M_{tot} = $M_{B tot}$ + M_{sp} = 1152 Nm

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